

- II. "The Functional Relations of the Motor Roots of the Brachial and Lumbo-Sacral Plexuses." By DAVID FERRIER, M.D., F.R.S., Professor of Forensic Medicine, and GERALD F. YEO, M.D., F.R.C.S., Professor of Physiology in King's College. Received March 10, 1881.

The functions subserved by the plexiform arrangement of the nerves of the limbs, and the mode of distribution of the several roots of the brachial and lumbo-sacral plexuses, have been the subject of frequent speculation and of occasional experimental research; and the question is one of considerable physiological and pathological interest. A mere naked-eye examination of the mode in which the roots unite to form the larger trunks allows of an approximate determination of the possible roots of each trunk; and by more minute dissection and maceration in dissociating liquids, as has been done by W. Krause in the case of the brachial plexus ("Beiträge zur Neurologie der Oberen Extremität," 1865), the constituent fibres of the nerve-trunks may be determined with greater precision.

But it is obvious that anatomical dissection, however minute, is unable to discriminate between the sensory and motor constituents of the nerve-trunks, or to indicate their functional relations and distribution. The only possible methods by which this can be arrived at are by determining the effects of excitation or destruction of the individual roots of the plexus.

Both methods have been employed by different investigators in the case of several of the lower animals.

Johannes Müller and Van Deen experimented on the crural plexus of the frog. From these, as well as from a consideration of the results of Kronenberg's experiments referred to below, Müller came to the conclusion that "the plexuses of nerves seem to be destined, as far as their motor power is concerned, to convey to each muscle fibres from different parts of the brain and spinal cord. . . . The plexuses may also be intended to intermingle the sensitive and motor fibres in accordance with the wants of the parts to which the nerves are distributed" (Müller's "Physiology," translated by Baly, vol. i, p. 682). Kronenberg ("Plexuum Nervorum Structura et Virtutes," Berol, 1836, quoted by W. Krause, *op. cit.*) found that by mechanical or electrical stimulation of the roots of the brachial plexus in the rabbit, almost every muscle of the limb was thrown into action by each. His conclusions as to the functions of the plexus were essentially the same as those quoted from Müller.

A similar view was maintained by Bartolomeo Panizza, from the results of experiment on the crural plexus of frogs and goats.

("Recherche Sperimentali Sopra i Nervi," Lettera del Professore Bartolomeo Panizza al Professore Maurizio Bufalini. "Annali Universali di Medicina," December, 1834. Translated in "Froriep's Notizen," No. 945, March, 1835.)

Panizza found that section of one root caused only temporary weakness of the limb as a whole, a weakness which increased in proportion to the number of roots divided; but there was no complete paralysis till the last root was cut. He was of opinion that the various roots had a community of function, the whole forming a solidarity, but each by itself capable of maintaining the functions in their integrity.

The researches of Peyer ("Zeitschrift für Rationelle Medicin," N. F., Bd. iv, 1854) on the peripheric distribution of the sensory and motor roots of the brachial plexus in the rabbit were of greater precision than those of Kronenberg.

Peyer cut the roots of the plexus and ascertained, by exposure and dissection, which muscles were made to contract by weak electrical stimulation of each root. He also determined the region of distribution of the sensory roots by cutting all the roots save one, and then ascertaining in which area cutaneous stimulation still excited reflex movements.

The results obtained by Peyer as to the distribution of the motor roots differ considerably from those of Kronenberg, and he gives, in a tabular form, the respective muscles related to each root, from the fifth cervical to the first dorsal.

He found that most muscles received fibres from more than one root, and that the muscles supplied by each root did not fall into such simple groups as extensors, flexors, &c., but were more complicated. The muscles nearer the hand were supplied by the roots nearer the dorsal part of the cord. As regards the sensory distribution, the rule was that the sensory roots were distributed to the cutaneous surfaces overlying the muscles supplied by the corresponding motor roots.

Peyer's results were, in the main, confirmed by the researches of W. Krause ("Beiträge zur Neurologie der Oberen Extremität," 1865). Krause adopted the method of dividing the individual roots and then tracing the lines of degeneration in the sensory and motor nerves, according to the Wallerian law. He gives a tabular view of the peripheric distribution of the various roots, sensory and motor, in the work quoted, and again, with slight variations, in his work on the anatomy of the rabbit ("Anatomie des Kaninchens," 1868, p. 247).

Krause also made one interesting experiment on a monkey (*Macacus cynomolgus*). He divided the sixth and seventh cervical nerves, and ascertained that no degeneration ensued in the ulnar or median sensory nerves of the hand. He concluded, by analogy from the ascertained distribution in the rabbit, that the ulnar and median

digital nerves were derived from the first dorsal and eighth cervical nerves respectively.

Passing from these experimental researches in the lower animals to observations in man, we have a fact of considerable significance in reference to the functional relations of the roots of the brachial plexus, which was first pointed out by Erb ("Diseases of the Peripheral Cerebro-Spinal Nerves," in Ziemssen's "Cyclopædia of the Practice of Medicine," vol. xi, p. 561). By faradisation over the brachial plexus; at a point corresponding with the exit of the sixth cervical nerve from between the scaleni muscles, the deltoid, biceps, brachialis, and supinator longus can be thrown into simultaneous contraction. At the same time, he says it is difficult to avoid the musculo-spiral nerve, which can also, however, be separately excited. We have ourselves found extension of the wrist a constant accompaniment of the action of the above muscular group when it is at all distinct. From the collocation of the muscles affected in atrophic spinal paralysis, it has been ably argued by E. Remak ("Zur Pathogenese der Bleilähmungen, Archiv für Psychiatrie," 1876; and "Ueber die Localisation Atrophischer Spinallähmungen und Spinaler Muskelatrophien," *ibid.*, 1879) that functionally related or synergic muscles are represented together in the anterior horns of the spinal cord; and he indicates, more or less tentatively, the probable position of the centres of certain brachial and crural muscular groups in the cervical and lumbar portions of the cord respectively.

With the view of throwing light on these various questions by physiological researches, which may be regarded as almost directly applicable to man, we have made a series of experiments on the motor roots of the brachial and lumbo-sacral plexuses in monkeys.

The brachial plexus in the monkey corresponds in its constitution, configuration, and distribution almost exactly with that of man. It is formed by roots from the fourth, fifth, sixth, seventh, and eighth cervical, and the first dorsal nerves. These unite and form the larger nerve-trunks in essentially the same way as in man. The phrenic nerve, however, arises from the third and fourth cervical, and does not, so far as we have examined, receive a branch from the fifth, as is usually the case in man.

The lumbar and sacral plexuses, however, do not at first sight appear to correspond, at least as regards the origin of the roots which enter into their composition. This is owing to the fact that there are seven lumbar vertebræ in the monkeys we have examined. If, however, we detach the first lumbar vertebra and add it to the dorsal, so as to make thirteen dorsal vertebræ, and count the last lumbar as the first sacral, the harmony, as regards the mode of distribution of the several roots, becomes complete. And, in one case which we examined, there were rudimentary ribs attached to the first lumbar vertebra. It

seems, in fact, warrantable to make the constitution of the lumbar and sacral plexuses a means of determining to which group the variable dorsal, lumbar, and sacral vertebræ in monkeys should be referred.

The mode of operation carried out by Dr. Yeo was as follows:—The animals were deeply narcotised with chloroform, the vertebræ over the cervical or lumbar nerves exposed, the arches removed so as to expose the cord. The dura mater was opened, and in the case of the cervical and dorsal nerves the posterior roots were cut in order to avoid all reflex movements on stimulation. In the case of the roots forming the cauda equina this was not necessary, as the anterior and posterior roots run a long separate course, and can easily be isolated. The motor roots were stimulated with closely approximated needle electrodes by means of the induced current of Du Bois Reymond's secondary coil. A minimal current, barely perceptible on the tongue, and just sufficient to produce distinct action, was employed, the distance of the secondary coil varying from 20 centims. or less, according to the degree of excitability of the nerves, which is liable to considerable variation at various stages. Every precaution was taken to insulate the roots, and unavoidable diffusion was more or less eliminated by frequent repetition and uniformity in the results. Occasionally, in the case of the brachial plexus, where the clear exposure of the roots is somewhat difficult, we used as one pole a flat electrode over the sacrum as a neutral point, and stimulated the root by hooking it up on a curved needle, which formed the other pole of the circuit. The roots were stimulated either inside or outside the sheath, according to where they were most conveniently reached.

In observing the effects of stimulation, we directed our attention more especially to the resultant muscular combination rather than to the mere number of the muscles thrown into action. It will be seen that this is of no little importance, as the actions excited are all complex co-ordinated movements of great significance. It is very difficult, where so many events are occurring simultaneously, to analyse each muscular combination into the individual factors at work; and therefore the muscles which we state to be in action are those which we have collected from various observations, the muscles being felt or partially exposed where it was difficult to be sure of their co-operation otherwise. But we would not exclude, except when so stated, the co-operation of other muscles which were necessarily removed from actual observation, except by dissection.

But we believe that these may be fairly determined by anatomical considerations and by ascertained principles respecting the physiology of movements applied to the individual actions described.

We have experimented seven times on the brachial plexus, once unsuccessfully; and six times on the lumbo-sacral plexus, twice with only partial success on two roots.

The resultant actions have been very uniform, though occasionally incomplete, any variations of importance being specially indicated.

The Brachial Plexus.

Comprising the roots of the first dorsal, and the eighth to the fourth cervical.

First Dorsal.—*Adduction of the thumb, and flexion of the fingers at the metacarpo-phalangeal joints.*—The distal phalanges are slightly extended, and the fingers spread. The transverse diameter of the hand is diminished, and the dorsal aspect rendered more convex.

The action is that of the intrinsic muscles of the hand. Along with the action in the hand there is also contraction of the muscles on the same side of the neck, causing the head to be drawn towards the shoulder.

In our first two experiments this action was more or less complicated by that described under the eighth cervical, due without doubt to imperfect isolation of the irritation.

Eighth Cervical.—A complex action comprising *firm closure of the fist* (intrinsic muscles and long flexors of fingers and thumb), *pronation and flexion of the wrist* (to the ulnar side), *extension of the forearm with retraction of the upper arm* (long head of the triceps specially in action). The *extensor muscles* on the back of the forearm generally were specially observed in two instances to be rigid also.

The action here described may be exactly imitated by pulling some object hanging in front downwards and towards the hip, or by drawing a scimitar from heel to point through some object lying in front.

The muscles involved imply stimulation of nerves conveyed in the ulnar, median, and musculo-spiral.

The pectoralis major seems also to co-operate in this movement in man, but it was not specially observed in our experiments, though the shoulder was observed to be depressed. This would imply also the internal anterior thoracic, which anatomically is related to the cord formed by the eighth cervical and first dorsal.

Seventh Cervical.—The *upper arm is adducted, rotated inwards and retracted*, and the *forearm extended* so as to bring the dorsum of the hand against the rump, the *wrist and fingers flexed* (at their second phalanges), so as to bring the tips of the fingers towards the radial side and against the rump.

The action here described is the *sculptor ani* movement, and involves the co-operation of numerous muscles. The teres major, latissimus dorsi, and subscapularis appeared to be in action. The pectoralis major was noted in one instance also. The triceps was also observed to be contracting, and also the long flexors of the fingers.

These muscles would indicate stimulation of nerve-fibres contained

in the subscapulars, musculo-spiral, and median—possibly also the external anterior thoracic to the pectoralis major.

Sixth Cervical.—The upper arm is *adducted and retracted*, the *forearm extended and pronated*, the *wrist flexed*, and the palm of the hand brought against the pubes.

This movement generally occurs quickly, and the palm of the hand is brought smartly backwards towards the middle line.

It seems to be the action which, if the hands were the fixed point, would raise the body upon a trapeze or branch.

We noted the contraction of the pectoralis, the latissimus dorsi, triceps, and flexors of carpus. The pronators were also evidently in action, though not visible.

These muscles imply stimulation of the external anterior thoracic, long subscapular, and branches of the musculo-spiral and median nerve.

Fifth Cervical.—The *upper arm is raised upwards and inwards*, the *forearm flexed and supinated*, the *wrist and basal phalanges extended*. The fingers assume a claw position with their distal phalanges bent.—The result of this action is to bring the hand up to the mouth. Among the muscles in action we specially noted the deltoid, its clavicular portion more particularly, the serratus magnus, the flexors of the forearm—biceps, brachialis anticus, and supinator longus. Also the extensors of the wrist and basal phalanges.

These muscles imply stimulation of nerves conveyed by the circumflex, musculo-cutaneous, and musculo-spiral, and apparently also the median (long flexors of fingers).

Fourth Cervical.—The *shoulder and upper arm are raised upwards and backwards*, the *forearm flexed and supinated (and the wrist extended)*.—The action here is in other respects similar to that of the fifth cervical, except in the raising the arm upwards and backwards. The muscles we observed in action were the deltoid, the rhomboid, the supra- and infra-spinatus muscles, the flexors of the forearm and extensors of the wrist, though occasionally the last were not observed.

During stimulation of this root respiration ceases from *spasm of the diaphragm*.

The action described implies stimulation of fibres conveyed by the rhomboid, supra-scapular, circumflex, musculo-cutaneous, and musculo-spiral nerves, and also of the phrenic.

We would likewise note a fact which may require further investigation, viz., that in one case in which we specially directed attention to the pupil, during stimulation of the motor roots from the first dorsal up to the fourth cervical, no action on the pupil was observed, though the usual movements of the limb occurred. This is a fact which is of importance in reference to the question of a cilio-spinal centre in the lower cervical region of the cord.

At present we merely note the above fact, reserving the subject for future inquiry.

The Lumbo-Sacral (Crural) Plexus.

The roots which supply motor fibres to the lower extremity comprise the first sacral, seventh, sixth, fifth, and fourth lumbar in the monkey, corresponding, as already indicated, to the second sacral, first sacral, fifth, fourth, and third lumbar in man respectively.

Stimulation of the second sacral, and of the third and fourth sacral in the instance where we exposed these roots, gave rise to movements of the tail. We could not determine movements of the pelvic muscles.

First Sacral (second sacral in man).—*Adduction and flexion of hallux* (basal phalanx), *flexion of the proximal phalanges of the toes* with slight separation and extension of the distal phalanges. The tail also moves to the same side.—The action here is identical with that of the first dorsal in the brachial plexus, and is due to the intrinsic muscles of the foot.

Seventh Lumbar (first sacral in man).—*Flexion of the leg* (hamstrings), *plantar flexion of the foot* (sural muscles), *adduction of the hallux and flexion of the toes at the proximal phalanges* (as in first sacral) with the addition of *flexion of the hallux at the distal phalanx* (long flexor).—The thigh is slightly rotated outwards, so that the plantar aspect looks towards the middle line.

The tibial and peroneal muscles and long flexors of the fingers do not act.

The nerves in action are branches of the great sciatic and its internal popliteal divisions.

Sixth Lumbar (fifth lumbar in man).—*Rotation outwards of thigh* (which assumes a position midway between extension and flexion), *flexion of the leg with inward rotation*, so that the foot points inwards, *plantar flexion of the foot with flexion of the hallux and toes at their distal phalanges*. The outer edge of the foot is somewhat raised.—This complex action involves the co-operation of many muscles difficult to analyse. We noted action of muscles in the gluteal region, the hamstrings, sural muscles, long flexors, the tibialis anticus and posticus, the peroneal muscles, and also the extensors of the toes.

This involves stimulation of nerves from the trunk, and from the external and internal divisions of the great sciatic nerve.

Fifth Lumbar (fourth lumbar in man).—*Extension of the thigh, extension of the leg and pointing of great toe*.—The combined result is straightening of the whole limb directly backwards, and seems to be the movement which immediately precedes the lifting of the foot to take another step forward in the act of walking.

The muscles we observed in action are the gluteal, the adductors, extensor cruris, and the peroneus longus. This latter explains the pointing of the great toe by depression of the base of the first metatarsal bone; and at the same time the raising of the outer edge of the foot. The sural muscles did not appear to contract.

This apparently involves stimulation of nerves conveyed by the superior gluteal, anterior crural, obturator, and musculo-cutaneous branch of the external popliteal nerve.

Fourth Lumbar (third lumbar in man).—*Flexion of the thigh* on the pelvis and *extension of the leg*.—This brings the leg in the line straight forwards.

In addition to the ilio-psoas (evidently in action, though not visible), the sartorius, adductors, and extensor cruris were observed to contract. No action was observable in the muscles of the leg or foot.

The nerves involved are conveyed by the anterior crural and obturator trunks.

Stimulation of the *third lumbar* (second in man) caused contraction of muscles in the flank, but no action in the leg. The cremaster muscle was not observed, though its contraction should be expected here. Stimulation of the *second* (first in man) and of the *first* lumbar nerves caused contraction of some muscles in the flank and hypogastric region.

It will be seen that the movements which result from stimulation of the individual roots of the brachial and crural plexuses are not mere contractions, more or less strong, of various muscles (though many muscles are excited to contraction by more than one root, as previous experimenters have found), but a highly co-ordinated functional synergy in each case, as Remak has supposed.

The muscles thrown into action by each root are innervated in most cases by several nerve-trunks, whence it would appear that the plexiform junctions of the various roots are for the purpose of distributing the requisite motor fibres in different trunks to the various muscles engaged in each functional combination.

The result of section of each motor root would, therefore, be paralysis of the corresponding combination, not necessarily, however, of the individual muscles involved. For, as many of these are innervated by more than one root, the degree of paralysis of the muscles would depend on the degree of motor innervation by the root divided; and, therefore, while weakened, they might yet act in other combinations in so far as they were supplied by other roots. Such appears to us the real explanation of the fact stated by Panizza, that there was no absolute immobility of the limb in his experiments until every root was cut.

It is evident that the cervical and lumbar enlargements of the spinal cord are centres of highly co-ordinated muscular combinations. These (as Krause's researches on rabbits, compared with ours, would seem to

indicate) may differ in different animals according to their habits and modes of activity.

The results we have obtained are capable of numerous physiological and pathological applications, but for the present we content ourselves with the above brief statement of some of the more obvious conclusions which they seem to justify.

III. "On the Histology and Physiology of the Pepsin-forming Glands." By J. N. LANGLEY, M.A., Fellow of Trinity College, Cambridge. Communicated by Dr. MICHAEL FOSTER, F.R.S. Received March 11, 1881.

(Abstract.)

This paper contains an account of observations upon *Rana temporaria*, *Bufo vulgaris*, *Triton taeniatus*, *Triton cristatus*, and *Coluber natrix*.

In these animals the changes which take place in the pepsin-forming glands under various conditions, viz., digestion of varying amounts of food, attempted digestion of indigestible substances, as sponge, and fasting, were noted.

Omitting the pyloric glands, which in these animals form only a minimal amount of pepsin, all the pepsin-forming glands present certain phenomena in common. In all, the living gland-cells contain granules, which diminish during digestion. In each the amount of pepsin* contained by a definite weight of the gland-bearing mucous membrane is proportionate to the amount of granules contained by the gland-cells. An increase or diminution of the cell-granules, in whatever way it is brought about, is accompanied by a corresponding increase or diminution in the pepsin-content of the cells. Further, in different parts of the pepsin-forming region the amount of pepsin present is proportional to the granularity of the cells.

Hence we may conclude that the granules consist wholly, or in part, of pepsin or of some substance capable of giving rise to pepsin.

In some of these animals certainly, and probably in all, the fresh glands contain only a minimal quantity of pepsin, but, on the other hand, a large quantity of a substance from which pepsin can be obtained, i.e., zymogen. It follows, then, that in the previously mentioned estimation of pepsin, the pepsin found resulted from the splitting up of zymogen, and consequently that the amount of zymogen contained by the gland-cells is proportional to their granularity.

* The dried mucous membrane was extracted with one hundred times its weight of hydrochloric acid, 0.2 per cent. Grützner's colorimetric method was used in making the estimations.